REMARKS

Several amendments have been made to the claims. The independent Claims 1 and 9 have been amended to specify that the array transducer is a two dimensional array transducer as stated on page 8, lines 1-4 of the specification and shown in Fig. 11 at #12. These claims also now recite that the point spread function of each beam is controlled in both the azimuth and elevation dimensions, since this is a volumetric application. This is found on page 10, line 20 through page 11, line 11 in the discussion of the drawings of Fig. 12. Grammatical errors have been corrected in Claims 7 and 8. To simplify the application Claims 17-22 have been canceled.

Claims 1-9, 11, and 12-16 were rejected under 35 U.S.C. §102(b) as being anticipated by US Pat. 6,374,674 (Mine). Amended Claim 1 describes an ultrasonic diagnostic imaging system for three dimensional scanning comprising a two dimensional array transducer having a plurality of transducer elements; a beamformer coupled to the array transducer which causes the transducer to scan a volumetric region with a plurality of transmit beams and to receive echo information in response to transmit beams, the beamformer controlling the point spread functions of beams transmitted and/or received by the beamformer in the azimuth and elevation dimensions; an image processor coupled to the beamformer which produces image signals in response to the echo information; and a display coupled to the image processor, wherein beams produced by the beamformer exhibit a first point spread function when the volumetric region is scanned with a first line density and a second point spread function when the volumetric region is scanned with a second line density. An ultrasound system of the present invention can coordinate the point spread function of the ultrasound beams with the line density of the volumetric region being imaged to produce the desired spatial sampling of the volumetric region. Ideally, the point spread function will be sufficient to satisfy the Nyquist criterion for spatial sampling and not produce scintillation artifacts, yet not to such a degree that the frame rate for real time imaging will degrade. Different users may desire other tradeoffs depending upon their imaging system objectives.

The Mine patent is not concerned with spatial sampling and never mentions point spread function. Mine is concerned with signal-to-noise and resolution of his images (see col. 3 at lines 28 and 42) because he is using very small transducer elements (col. 1, lines 34-39) which transmit a low level sound pressure. What Mine is doing is imaging a volume of three dimensional space in real time 3D imaging with one transmitting/receiving condition and a cross sectional (2D) image as a high quality image with a second transmitting/receiving condition. See col. 2, lines 7-12 of Mine. The difference between the two conditions is that the number of signals received in parallel for the 3D image is greater than the number of parallel signals for the high quality 2D image. The two images are shown in Mine's Fig. 3, where the 2D image is seen to be within the volume region of the 3D image. Mine is maintaining a frame rate of display for the 3D image above 20 Hz (col. 6, lines 40-41) by virtue of his use of multiline reception in 3D. Multiline is done by transmitting a broad transmit beam (Mine calls it a "massive transmit beam") as shown in US Pat. 4,644,795 (Augustine) which encompasses the locations of several receive lines as shown in Mine's Fig. 2a. The broader one can make the beam, the greater the number of lines which are insonified by the beam and hence the shorter the time to scan the entire volume, which produces his desired high 3D frame rate. But with the broad beam used for 3D imaging, Mine recognizes that the sound pressure from the transducer elements is dispersed over a greater volume and thus the echoes returning are weaker and exhibit a poor S/N ratio. The image will thus be noisy and not with the high sensitivity or resolution that Mine would like. Mine cannot solve this problem for his 3D image and still produce real time 3D images above 20 Hz., but he does address it when he scans the fine 2D cross section. When he scans the 2D plane, Mine does so with a lower order multiline, that is, each transmit beam is narrower so that its energy density is greater. In the example Mine shows in Fig. 2b, Mine does not use multiline at all but conventional single line imaging. Because the energy of each transmit beam is confined to a smaller region when doing 2D scanning, the sound pressure insonifying each receive line location is greater and returns stronger echo signals, providing a better S/N ratio and thus improved sensitivity and resolution. Mine is thus interleaving two scanning modes at the same time, although the two modes are independent. See col. 5, lines32-34. When he scans his 3D volume, Mine is doing so with high order

multiline reception. When he scans his 2D cross section, he does so with low order multiline or no multiline at all.

What point spread function is being used in the 3D scanning? Mine does not say. What about the 2D cross section image? Again, we do not know. Mine appears to be using one point spread function for 2D imaging and another for 3D imaging. But he never says anything about any point spread function changes when changing the multiline order for the scanning. He says nothing at all about different orders of multiline. Mine never discusses changing multiline order for 3D. His concern is with frame rate.

Is one or the other of Mine's 3D or 2D images spatially undersampled? Again we do not know. Mine never intimates a problem with shimmering or scintillation artifacts, the signature of undersampling which is addressed by the present invention, so the most likely answer is that he is always oversampled spatially, which is indicated by the fact that he transmits "beams toward a plurality of focus points several times" (col. 5, lines 43-44). As an analogy, suppose one were looking at two television screens which were viewing a golf course. One of the sets is a conventional 525-line set, and the other is a high definition 1080-line set. On the conventional set the grass would appear as an expanse of green, but on the high definition set the viewer would see the texture and perhaps even individual blades of grass. Which set is spatially undersampling the view of the golf course? Neither is, because the golf course does not appear to shimmer or scintillate. Both are oversampled, but the HD set is more greatly oversampled with very dense scan lines so that the grass of the golf course is more highly resolved in the image. This is what Mine is trying to do, more greatly oversample his cross sectional image so that its resolution and sensitivity are better than that of the 3D image. He says nothing about changing his point spread function, nor does he allude to spatial undersampling or its effects.

The Examiner points to col. 4, lines 55-59 to suggest that Mine is controlling his point spread functions for volume imaging but the cited passage only describes conventional beamforming. A simple example shows this. Suppose you were dropping a pebble in the center of a bucket of water and observing the ripple pattern. You would see a wave which is an ever-expanding circle expanding outward from the point where the pebble hit the water.

Suppose you measure the time elapsed from the moment the pebble hits the water until the moment the expanding circular wavefront reaches the side of the bucket. Suppose you dropped another pebble and measured the time again. Each measurement would be the same. That is because the speed of the wavefront in the water is a fixed physical constant. In diagnostic ultrasound the speed of sound in the body (1550 meters per second) is also a fixed physical constant.

Now suppose you go to the water tank W in enclosed Exhibit 1. At the near end of the tank are three transducers A, B, and C at the surface of the water. In the center of the tank is a solid target shown by the circled "T". Suppose you vibrated the transducer A and observed its wavefront. It would again be an ever-expanding circle radiating out from the transducer A. An arc of the wavefront A is shown at the moment the wavefront reaches the target T. The wavefront A will thereafter continue to radiate outward as indicated by the attached arrows. You could predict in advance the time it takes for the wavefront to travel from the transducer A to the target T because you already know its speed from the bucket experiment, and you can measure the distance to target T. Time and distance are thus directly related to each other.

Now suppose you vibrated the transducers B and C which are laterally disposed equidistant on each side of transducer A. Their wavefronts B and C from these transducers are shown at the moment they reach the target T. But it takes longer for these wavefronts to reach the target because the distance from each transducer to the target T is greater than the A - to - T distance. If you timed the vibrations so that all 3 wavefronts arrived at the target at the same time, you would have a bit of the energy of each of the wavefronts reflected back from the target T at the same time. In this condition the transmitted waves are focused at the target T. You would vibrate the transducers B and C first, since their wavefronts have to travel further to reach the target. You would then wait (delay) awhile until the exact moment came to vibrate transducer A so that all 3 wavefronts would converge on the target T at the same moment. You could precisely calculate this delay time in advance by knowing the distances to the target and the speed of travel of the wavefront. This is how a transmit beamformer operates.

When the wavefronts converge on the target T, the target reflects back some of the energy of the waves in an echo wavefront. Like the others, this echo wavefront is an ever-increasing circle. A portion of the echo wavefront is shown at E, when a small arc of it has almost reached the A transducer. It can be seen that after the wavefront E reaches transducer A, it will be sometime later before the wavefront reaches the B and C transducers. So you will sample the signal at transducer A at the moment the wavefront E arrives, then wait (delay) until the time when the wavefront reaches the B and C transducers, at which point you will sample their signals. When you add the three together you will have a combined signal of three parts of the wavefront, because your sampling was done "coherently" and you have "focused" the signals received from target T.

But will you only have those three signals? No, because all of the targets in the tank are constantly returning their own echoes as they are encountered by wavefronts from the transducers. Each transducer is receiving a continual stream of echoes, which will produce a jumble of noise, a noise floor in your combined signals. But these other echoes are virtually random and not coherent, since you timed your sampling to be coherent only for the point of target A. Thus, the signal from target A will rise above this noise floor. If it rises high above the floor, there is a strong reflector at the target A location. If you see only the noise floor, you will know there was no target at that location. You will paint a spot at that location of your sound image field accordingly. This is exactly how B mode (amplitude) receive beamforming works. The passage cited in column 4, lines 55-59 of Mine says to do this repeatedly for transmissions in different directions toward all of the target locations in the image field. This says nothing about point spread function control.

The Examiner also points to col. 10, line 63 to col. 11, line 1 which mention aperture and aperture function. But this is a passage where Mine lists all of the possible imaging parameters which can be different between his 3D and 2D transmitting/receiving conditions. The fifteen parameters he lists are (1) sound pressure, (2) a central frequency, (3) bandwidth, (4) wave form and pulse cycles of a transmitted ultrasonic beam, (5) an aperture size of a transmitting side, (6) a transmitting focus point, (7) a weighting function of a transmitting ultrasound on an aperture, (8) a central frequency and band of a receiving ultrasonic beam, (9) an aperture size at a receiving side, (10) a receiving focus point, (11) a

weighting function of a receiving ultrasonic on an aperture, (12) a raster density of transmitting/receiving signal, (13) a Doppler mode, (14) a harmonic mode and (15) a B mode. It is true that Mine includes aperture sizes (both transmit and receive) and aperture weighting function (also for both transmit and receive) in his list. These are all parameters which may differ between the 3D scanning mode and the 2D cross sectional scanning mode. But Mine gives no guidance as to how these functions should be varied between 3D and cross sectional imaging, nor any indication of what changes or effects may result. This is simply a laundry list from which a user may choose to vary any number of parameters in unspecified ways.

For the foregoing reasons it is respectfully submitted that Claim 1 and its dependent Claims 2-8 are not anticipated by Mine.

Amended Claim 9 describes an ultrasonic diagnostic imaging system for three dimensional scanning comprising a two dimensional array transducer having a plurality of transducer elements; a beamformer coupled to the array transducer which causes the transducer to scan a volumetric region with a plurality of transmit beams and to receive echo information in response to transmit beams, the beamformer controlling the point spread functions of beams transmitted and/or received by the beamformer in the azimuth dimension and the elevation dimension by control of the aperture function of the array transducer; an image processor coupled to the beamformer which produces image signals in response to the echo information; and a display coupled to the image processor, wherein the beamformer utilizes a first aperture function when the volumetric region is scanned with a first line density and a second aperture function when the volumetric region is scanned with a second line density. An ultrasound system of Claim 9 uses the beamformer to control the point spread function of beams in both the azimuth dimension and the elevation dimension by control of the aperture function of the two dimensional array transducer. The beamformer utilizes a first aperture function when a volumetric region is scanned with a first line density and a second aperture function when the volumetric region is scanned with a second line density. The description of Mine's beamformer and its operation in col. 4, lines 45-59 does not show or suggest any control of point spread function or control of an aperture function, nor the control of point spread function in both the azimuth and elevation dimensions. The

description is, as explained above, that of a conventional beamformer. While the laundry list of parameters which may differ between the 3D volume scanning mode and the 2D cross sectional fine imaging mode in col. 10, line 61 to col. 11, line 3 includes mention of aperture sizes and weighting functions, this is no more than an offer to experiment, for Mine does not tell how to vary these parameters or what results may be obtained. More significantly, the parameter differences are between 3D and 2D imaging modes and not for different line densities and point spread functions in 3D. As previously indicated, there is no mention of point spread function at all in Mine, nor is Mine concerned about spatial sampling. For all of these reasons it is respectfully submitted that Claim 9 and its dependent Claims 10-16 cannot be anticipated by Mine.

Claims 10 and 13 were rejected under 35 U.S.C. §103(a) as being unpatentable over Mine in view of US Pat. 6,282,963 (Haider). Haider was cited for its mention of apodization in the abstract. Haider is using apodization, not to control the point spread function for effective spatial sampling, but to be able to receive dual beams without warping. The problem is shown in Fig. 4. When a receive beam is received in line with the center of the transmit beam, line 42 in Fig. 4, a straight line beam is received. But when the receive beam is to the left or right of the center of the transmit beam, the receive beam will be bent or warped toward the center of the transmit beam in the vicinity of the transmit focal point. This problem is better illustrated in Fig. 7 of US Pat. 5,623,928 (Wright et al.) where two adjacent transmit beams are shown in line with arrows T_0 and T_2. When a beam R_{01} is received to the right of center of the T_0 transmit beam it will be warped to the left toward the transmit beam focus as shown by the dashed line to the right of the T_0 beam center. When a beam R_{21} is received to the left of the second transmit beam T_2, it is warped to the right toward the focal point of T_2 as shown by the dashed line to the left of the T_2 beam center. Ideally, Wright et al. would not like to have this warping because they want to combine these two receive beams into one. But what they do is interpolate the two beams laterally. When each receive beam is offset from its transmit beam center by the same distance, the curvature of the warping of each receive beam is the mirror of the other. Lateral interpolation will thus interpolate receive beam signals in a straight line between the two

reciprocally warped receive beams as illustrated by the straight line between the two dashed lines.

Haider has a different approach to this problem. He proposes to use transmit apodization to shape the beam profile with two main lobes instead of one, the solid line beam profile in his Fig. 3 as compared with the dashed single lobe profile. He then receives his two beams at the same time, one aligned with the center of the left lobe and the other aligned with the center of the right lobe. Since each is centered in its lobe, it is expected that there will be no warpage of the received beams. This is how he does his transmission for a full image. He uses the same transmit apodization for each transmit to transmit a two-lobe beam each time and receives two lines from each transmission. In this way he can double his frame rate as it only takes half the time to scan the full image field. Like Mine, he can use this 2-line multiline technique to improve his frame rate.

Haider gives no information on his spatial sampling. He does not suggest that he is controlling the aperture function of a two dimensional array transducer to control the point spread function in azimuth and elevation. Since Haider is using a 1D array transducer (10), it is only possible for him to control the beam profile in one dimension. And he does not suggest using different aperture functions when a volumetric region is scanned with different line densities. The is because he is only doing two dimensional imaging. Thus, when Haider is combined with Mine, the combination continues to lack several of the features called for by Claim 9. Since Claims 10 and 13 both depend from Claim 9, it is respectfully submitted that they are patentable over Mine and Haider by reason of this dependency.

In view of the foregoing amendments and remarks, it is respectfully submitted that Claims 1-9, 11, and 12-16 are not anticipated by Mine and that Claims 10 and 13 are patentable over the combination of Mine and Haider. Accordingly it is respectfully requested that the rejection of Claims 1-9, 11, and 12-16 under 35 U.S.C. §102(b) and of Claims 10 and 13 under 35 U.S.C. §103(a) be withdrawn.

In light of the foregoing amendment and remarks, it is respectfully submitted that this application is now in condition for allowance. Favorable reconsideration is respectfully requested.

Respectfully submitted,

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